

Indiana Department of Environmental Management
Office of Land Quality
P.O. Box 6015
Indianapolis, IN 46206-6015
OLQ PH: (317) 232-8941
OLQ FAX: (317) 232-3403

Enclosure E2 (Formerly referred to as Attachment E2)

**CONSTRUCTION QUALITY CONTROL AND
CONSTRUCTION QUALITY ASSURANCE
(CQC/CQA)
FOR GEOMEMBRANE LINER**

This document puts forth guidance regarding construction of land disposal facilities with Geomembrane liners. This document should not be construed as Agency policy in this regard, but rather, as guidance to staff and perhaps to the regulated community. It is recommended that this guidance be used for preparation of the CQC/CQA plan for a permit application for a new landfill (facility), and a permit modification for horizontal and vertical expansions. The CQC/CQA for the type of application must be submitted along with the new permit application/modification.

At a minimum, the following information, evaluation, calculations and/or narratives should be incorporated in the CQC/CQA plan.

1. Defining owners/contractors and subcontractors qualifications and responsibility during the construction of the facility. At a minimum, the following items shall also be defined.
 - C Owner delegation of authority
 - C Owner/operator relation to others
 - C Design engineer relation to others
 - C Manufacturer/installer relation to others
 - C Weather, work stoppage and sample custody
 - C CQC Personnel relation to others
 - C Independent QC/QA testing/laboratory services contractors.
2. CQC and CQA personnel qualifications, responsibilities and authority. The CQA officer, CQC inspector(s) and all other CQC/CQA personnel must have adequate training and related experience to perform their responsibilities. At a minimum, the following individual qualifications must be addressed where applicable:
 - C Manufacturer/Fabricator
 - C CQC/CQA personnel, etc.
3. Engineer oversight and certification responsibilities during the construction of the facility.
4. Establishment and protection of construction grid system on site for horizontal and vertical control and reference of work. Use of laser type surveying equipment rather than grade stakes is recommended.
5. Construction activities such as soil testing, excavation/surface runoff control, foundation and/or subgrade preparation, observation and documentation.
6. Describe the inspection, sampling, testing methods and test frequencies to be employed during the construction of the facility to assure that the subgrade and installed liner system complies with the design requirements and specifications;
7. Acceptance/rejection criteria for specific tests as well as statistical verification methods such as control charts. ASTM E-178 may be used as a guidance.
8. Corrective actions to be taken if some part of the work failed to meet the design standards; problem identification and corrective action for defects and repair.
9. Manufacturing quality control and quality assurance.
10. Specifications of Geomembrane (GM): (Ref. 4) The following information/properties must be provided, where applicable, in order to evaluate performance of a GM for intended use:

10.1 Physical properties:

- Thickness
- Specific gravity
- Mass per unit area (weight)
- Water vapor transmission

10.2 Mechanical properties:

- Tensile strength at yield
- Tensile strength at break
- Elongation at yield
- Elongation at break
- Modulus of elasticity
- Tear resistance
- Impact resistance
- Puncture resistance
- Soil-to-liner friction
- Seam strength

10.3 Chemical properties:

- Ozone resistance
- Ultraviolet light resistance
- Chemical compatibility: Provide the results of GM/waste compatibility testing demonstrating that liner strength and performance are still adequate after exposure to representative leachate sample.

10.4 Thermal properties:

- Hot climate or conditions
- Cold climate or conditions

10.5 Biological properties:

- Stability to microbe attack

10.6 Durability properties:

- Liquid absorption
- Aging
- Constant stress (creep) behavior
- Cyclic stress (fatigue) behavior
- Dimensional stability

All testing must be performed in accordance with the American Society for Testing and Materials (ASTM), The Geosynthetic Research Institute (GRI), the Corps of Engineer (COE), the National Sanitation Foundation (NSF) or other current Industry Standards.

11. Specification of geocomposite (i.e., geotextile, geonet) (if applicable) (For more details and information, see references 4, 9, 10);

11.1 Physical properties:

- Thickness
- Specific gravity
- Mass per unit area (weight)

11.2 Mechanical properties:

- Compressibility

- Tensile strength
- Fatigue strength
- Burst strength
- Tear test
- Impact tests
- Soil-to-fabric friction tests
- Pullout (anchorage) tests
- Grab strength
- Puncture strength
- Porosity
- Percent open area (POA)
- Apparent opening size (AOS) or equivalent opening size
- Permittivity (Cross-Plane Permeability)
- Transmissivity (In-plane Permeability)
- Soil retention test

11.3 Endurance Properties

- Creep (sustained loading)
- Abrasion tests
- Long-term flow (clogging) test
- Gradient ratio (clogging) test

11.4 Environmental Properties

- Resistance to chemicals
- Resistance to temperature
- Resistance to light and weather
- Resistance to bacteria
- Resistance to burial deterioration

12. Preconstruction activities of GM

12.1 GM Manufacturer: The manufacturer of the GM, where applicable, should provide to the CQA officer of the facility and the permitting agency, at a minimum, the following information:

- a. Density of GM - The purpose of this property is to provide molecular structure and crystallinity of the product which, in turn, relates to mechanical properties such as tensile strength, deformation and chemical resistance.
- b. Melt flow index (rate) - The purpose of this property is to ensure molecular weight and rheological (deformation and flow of matter) characteristics of the product for high-density polyethylene.
- c. Percent carbon black - This is to ensure GM protection against ultraviolet radiation. Generally, between 2 to 3 percent of carbon black is used for most GM's.
- d. Additional test of polymer raw material may be required by a site-specific CQA Plan.
- e. Other types of test may be required to ensure that the product meets the design specifications.
- f. The completed GM should be tested to conform with current National Sanitation Foundation (NSF) 54 standards. This information is needed to insure that the final product meets the design specifications and also to establish a "fingerprint" (Background). The following tests where applicable, depending on the type of

GM being proposed, should be performed as finished product specifications:

- Thickness
- Tensile properties
- Tear resistance
- Puncture resistance
- Density
- Low temperature impact
- Dimensional stability
- Environmental stress crack resistance
- Ozone resistance
- Heat aging
- Volatility loss
- Carbon black content
- Carbon black dispersion
- Chemical resistance
- Specific gravity
- Hardness
- Hydrostatic resistance
- Water extraction
- Certification 100% virgin material used in product.

NOTE: For more details and applicable testing for a specific GM refer to the most current NSF 54 standard.

This information is needed to ensure that the polymer raw material complies with the manufacturer's product properties and performance requirements.

13. GM fabrication: (For more details and specific information see references 6, 9, 10). This applies where factory seaming is used to join smaller liner sections into large panels in order to have fewer field seams. Factory seams must be nondestructively tested. The CQA officer must review all the necessary fabricators quality control documentation.

14. GM transportation and storage: (For more details and specific information, see references 6, 9, 10, 11). The GM must be stored in a secured area and be protected from adverse weather. GM's are usually shipped in rolls or folded on pallets. The rolls or pallets of finished product delivered to the facility must show, at a minimum, the following information:

- Method of loading, unloading and transporting GM during installation
- Name of manufacturer/fabricator
- Product type
- Product thickness
- Manufacturing batch code
- Date of manufacture
- Physical dimensions (length and width)
- Panel number or placement according to the design layout pattern
- Direction for unrolling or unfolding the geomembrane.

15. Construction of GM: (For more details and specific information, see References 6, 9, 10, 11).

15.1 GM installation: Describe the procedure for installing the Geomembrane. The GM/GM installer must have adequate experience in handling the proposed product to be installed or have experience with a similar material. The Gm/GM installer must be approved or licensed by

the manufacturer of the GM. Demonstration must be provided to the owner/QA officer and the agency indicating that the installer has the ability to fulfill their responsibilities. The following consideration should be given during the GM installation:

- a. **Surface condition** - prior to installation of the GM on subgrade/subbase, the following items must be checked to ensure protection of the liner from damage:
 - Compacted as specified by soil liner CQC/CQA Plan;
 - Free of large rocks;
 - Free of cobbles;
 - Free of rubbish;
 - Free of roots;
 - Smooth and uniform surface;
 - Free of sudden changes in grade.
- b. **Climate conditions:**
 1. **Temperature** - desirable temperature for installation of GM ranges from (32°F to 120°F) or per manufacturer's recommendation.
 2. **Wind** - could interfere with the installation of the liner, i.e., cause misalignment of seams; cleanliness of seam area. Wind gusts of less than or equal to twenty (20) mles per hour are recommended.
 3. **Precipitation** - field seaming shall not take place during precipitation unless provisions are made to maintain a dry sealing surface.
- c. **Anchoring trenches** - the liner should be secured in a backfilled trench as soon as possible to prevent movement of the liner.
- d. Describe installation procedures and type of equipment to be used for placing drainage layer and protective cover over the GM.

15.2 Liner placement: (References 6, 9, 10, 11)

- a. **Shop drawing** - should be provided to show the following:
 - Panel size
 - Layout
 - Details
 - Seam location and identification number shown.
- b. **Site inspection** - prior to placement of the GM, an inspection must be conducted by the CQA officer or by the owner's representative and the installer to verify that the surface condition is acceptable for placement of the GM.
- c. **Deployment** - The following consideration should be given during the development of the GM:
 1. Panel should be positioned to minimize handling.
 2. Panels should be secured as soon as possible to avoid movement.

3. Bridging or stressed conditions should be avoided with proper slack allowance.
 - d. **Field seaming** - At a minimum, the following considerations should be taken into account during field seaming:
 1. Favorable weather conditions;
 2. The contact surfaces of material must be:
 - Clean of dirt
 - Free of dust
 - Free of moisture
 - Free of other foreign material
 3. The contact surfaces must be aligned with sufficient overlap and smoothed out.
 4. Seams must be tested per CQC/CQA plan, or as recommended per Table 1 to verify the integrity of the seams.
 5. Seam samples should be taken per CQC/CQA plan to the lab in order to verify the field seaming.
 - e. **Venting** - in the event that there is a possibility of gas build-up under the liner and final cover, an appropriate gas relief system may be needed.
 - f. **Inspection and repair** - during the placement of the GM, all the field seaming must be inspected and any defects must be repaired. Traffic must not be allowed on the lined area. All the necessary repairs to the liner must be made using the same type of material as provided per the CQC/CQA plan, or as recommended by the manufacturer.
 - g. **Lower/upper bedding layer placement** - (See references 6, 9, 10 for more details.) Sufficient lower bedding (referred to as three (3) feet recompacted clay liner) and upper (referred to drainage blanket and protective cover) must be provided above and below the liner to prevent rupture during installation and installation and operation. The upper bedding layer material must be placed on the GM as soon as possible to protect the liner from weather conditions, equipment, vandalism, etc.
 - h. **Final inspection and acceptance** - upon completion of the liner, the entire liner's joints, seams and mechanical seals must be inspected by appropriate personnel to insure the functional integrity. Below is a list of testing methods being utilized for integrity of liner.
 - Hydrostatic test
 - Vacuum
 - Ultrasonic
 - Air jet
- 15.3 GM seaming: Describe the techniques to be utilized to bond membrane liner seams. There are many techniques which are used to provide adequate factory and field seams.
- Below is a list of the most commonly used techniques.
- c Adhesive seams
- c Chemical adhesive

- C Contact adhesive

- C Extrusion seams
 - C Fillet
 - C Flat

- C Fusion seams
 - C Hot wedge
 - C Hot air

- C Chemical seams
 - C Chemical fusion
 - C Bonded chemical fusion

There are several factors which may affect the long-term performance of geomembrane seam strength. These factors are as follows:

- Long-term aging
- Moist environment
- Soil environment
- Chemical environment
- Constant stress under both normal and elevated temperature.

Special consideration should be given to selection of GM and site-specific conditions in reference to the above-mentioned concerns.

16. Engineering Analyses/Evaluation/Calculation: Engineering analyses must be provided where necessary based on the data gathered through a subsurface exploration, laboratory testing program and by other means. Geosynthetic design documentation shall address all of the elements listed in Table 2 in accordance with the selected design and shall include all applicable design values, assumptions, calculations, drawings, etc.

- 16.1 Transmissivity (See References 4, 5.) (If applicable, ASTM D 4617): Verify that leachate collection removal (LCR) synthetic provides adequate planar flow. A minimum factor safety (FS) of 10 is recommended. This requirement is needed if a geonet (GN) is used in lieu of a drainage blanket. In addition, the long term creep impact on the transmissivity of the geosynthetic must be evaluated using a minimum for FS of (5).

Suggested Analysis Procedure:

a. Required information:

- Landfill maximum height
- Density of waste
- Slope angle
- Slope length
- Leachate inflow rate
- Laboratory transmissivity data for GN (ASTM D 4716)

b. Define minimum transmissivity

- Regulation requires $3 \times 10^{-6} \text{ m}^2/\text{sec}$. (Based on one (1) foot of sand with $K \geq 1 \times 10^{-3} \text{ cm/sec}$.)
- One (1) foot hydraulic head based on solid waste regulation

c. Calculate maximum normal stress

Normal stress = H

where:

H = unit weight of fill (Waste, daily, intermediate and final cover)
= height of fill to top of LCR

d. Obtain laboratory transmissivity data for proposed GN.

e. Find factor of safety (FS) as follows:

$$FS = \frac{\text{Removal Transmissivity}}{\text{Required Transmissivity}}$$

- 16.2 Transmissivity (If applicable, ASTM D 4617): Determine long-term creep impact on transmissivity of GM/LCR synthetic. A minimum FS of 5 is recommended. This evaluation is needed if GN is used in lieu of a drainage blanket.

Suggested Analysis Procedure:

a. Required information:

- Landfill height
- Density of Waste
- Field gradient

- b. Calculate maximum normal stress.

- Normal stress = H

- c. Obtain long-term transmissivity data for the proposed GN. Minimum design life of fifty (50) years may be used.
- d. Project long-term transmissivity.
- e. Required transmissivity is $3 \times 10^{-6} \text{ m}^2/\text{sec.}$ per regulation.
- f. Find FS.

$$\text{FS} = \frac{\text{Long-Term Transmissivity}}{\text{Required Transmissivity}}$$

- 16.3 Permitivity (Flow normal to geotextile (GT) ASTM D 4491) (See References 4, 5.): Verify that a GT will allow leachate/liquid to flow through it. A minimum FS of 50 is recommended. This evaluation is needed if GN with a GT attached on either one or both sides is used in a lieu of a drainage blanket.

Suggested Analysis Procedures:

- a. Required information:
- Leachate inflow rate
 - Maximum head (1 foot head)
- b. Calculate required permitivity using the Darcy's Equation ($q = KiA$).
- c. Obtain GT/GC permitivity results per ASTM D 4491.
- d. Calculate FS

$$\text{FS} = \frac{\text{Actual GT/GC Transmissivity}}{\text{Required Transmissivity}}$$

- 16.4 Filter - Retention (If applicable, CW-2215) (See References 4, 1.): Compare grain size distribution of retained soil to opening size of GT to verify retention of particles. FS is not applicable. This evaluation is needed where GN (GT on one or both sides) is used in lieu of a drainage blanket. This criteria may also apply in other cases, based on a site-specific design.

Suggested Analysis Procedures:

- a. Obtain particle size of cover soil to be retained (ASTM D 422).
- b. Obtain apparent opening size (AOS) for GT.
- c. Evaluate filter criteria by the following methods:

Criteria #1:

$$O_{95} \text{ (AOS) of the Filter Fabric (Geotextile)} < 2 \text{ } d_{85} \text{ of the Protective Cover (Soil)}$$

This equation is intended to prevent particles of soil from flowing through the filter fabric (geotextile), and:

$$O_{95} \text{ (AOS) of the Filter Fabric (Geotextile) } > 2 D_{15} \text{ of the Protective Cover (Soil)}$$

This equation is intended to prevent the clogging of the GT.
AOS refers to the apparent opening size of the GT.

Criteria #2:

- For Soil \leq 50% passing the No. 200 sieve:
 $O_{95} < 0.59 \text{ mm}$ (i.e., AOS of the fabric \geq No. 30 sieve).
- For Soil $>$ 50% passing the No. 200 sieve:
 $O_{95} < 0.30 \text{ mm}$ (i.e., AOS of the fabric \geq No. 50 sieve).

- 16.5 Filter - Clogging (If applicable) (See References 4, 5.): Evaluate the influence of retained soil particles on the permittivity of a GT. FS is not applicable. This evaluation is needed when GN is used in lieu of a drainage blanket as well as separation between the drainage blanket and the protective cover.

Suggested Analysis Procedure:

- a. Information needed:
 - Soil sample from specific site
 - Specific GT proposed
 - b. Perform gradient ratio test (GR) by ASTM or Corps. of Engineers (CW-02215) standard using soil sample from a specific site.
 - c. Evaluate gradient ratio, $GR \leq 3$ is recommended.
 - d. Evaluate long-term flow test.
- 16.6 Strength - Settlement (If applicable) (See Reference 5): Evaluate ability of LCR synthetic to resist down-drag forces resulting from the subsidence of the contained waste. F.S. of 1.5 is recommended.

Suggested Analysis Procedure:

- a. Required material properties or information:
 - c Friction angle
 - c LCR-to-Waste - via direct shear test.
 - c LCR-to-FML - via direct shear test.
 - c Tensile Strength of LCR - wide-width tensile strength (ASTM D 4595).
 - c Density of waste
 - c Waste height
 - c Slope angle
- b. Evaluate tension in LCR.
- c. Obtain laboratory tensile strength (ASTM D 4595)
- d. Calculate FS:

$$FS = \frac{\text{Maximum Allowable Tensile Stress}}{\text{Total Shear/FT}}$$

- 16.7 Strain - Settlement (If applicable - ASTM D 4595) (Reference 5): The ability of the Geosynthetic layer to resist down-drag forces resulting from subsidence of the contained waste. A minimum safety factor of one and one-half (1 1/2) on ultimate stress is required.

Suggested Analysis Procedure:

- a. Required material properties - load-elongation curve for LCR.
- b. Estimate sidewall/sideslope settlement of waste.
- c. Obtain laboratory load-elongation data for LCR synthetic (yield strain), (ultimate strain)
- d. Estimate maximum strain in LCR due to settlement.
- e. Calculate FS

$$FS_{\text{yield}} = \frac{\text{yield strain}}{\text{yield settlement}}$$

$$FS_{\text{ult}} = \frac{\text{ultimate strain}}{\text{yield settlement}}$$

- 16.8 Tensile Stress: Down-drag at filling; evaluate GM stress generated during construction and operation of the interior side slope of the facility. A minimum FS of 5 on yield stress is recommended.

Suggested Analysis Procedure:

a. Required material properties/information

- Friction Angles

C LCR-to-Waste - via direct shear test
C LCR-to-GM - via direct shear test
C Tensile Strength of GM (T)
C Cell height
C Density of waste
C Slope angle
C GM thickness

b. Calculate GM Tensile Stress

$$\text{Stress} = \frac{T}{t} \quad \text{where } T = \text{Tensile Strength of GM} \\ t = \text{Thickness of GM}$$

c. Obtain laboratory GM yield stress.

d. Calculate FS

$$FS = \frac{\text{Yield Stress}}{\text{Actual Tensile Stress}}$$

16.9 Localized Subsidence (If applicable) (See Reference 5.): Evaluate strains induced in the GM by localized subsidence. This applies to final cover and the liner system. Subsidence prone areas include the following:

- Mine subsidence
- Sinkholes (Karst Topography)
- Excessive fluid removal

Suggested Analysis Procedure:

a. Required Material Properties/Information

- Tensile Strength of GM
- Thickness of GM
- Normal Stress
- Soil - GM friction angle - Via ASTM direct shear test

b. Estimate localized subsidence geometry

c. Obtain uniform strain:

$$\text{Settlement Ratio} = \frac{\text{Depth} = S}{\text{Width} = L}$$

- d. Calculate additional deformable length using the following equation:

$$X = \frac{f_u d}{2A f_t}$$

Where: f_u = ultimate stress for GM
 d = thickness of GM
 A = normal stress
 f_t = friction coefficient

- e. Revise strain using the following equation:

$$= [x L] / [L + 2x X / 2]$$

- 16.10 Stability of Final Cover: Evaluate the likelihood and extent to which final cover

components may slide with respect to each other. A minimum FS of 1.3 is recommended for slope stability if design parameters are adequately defined. The objective of final cover stability is to provide assurance against slope failure.

- 16.11 Anchor Capacity: (Reference 5) Verify anchor capacity and stresses in the liner.

FS of 1.2 is recommended.

Suggested analysis procedures:

- a. Required materials property:
 - Soil-to-GM Friction Angle - via direct shear test
 - Soil Friction Angle - via triaxial test
 - Soil Unit Weight (γ)
- b. Define anchor variables
 - Geometry
 - C Slope angle - 18.4° (3:1) is recommended.
 - C Embedment length
 - C Soil cover depth
 - C Anchor burial depth
- c. Calculate anchor capacity. Below is a list of some typical anchor trenches:
 - Horizontal anchor
 - V-shape anchor
 - Rectangular-shape anchor or standard (most commonly used).
- d. Calculate:

$$FS = \frac{\text{Allowable Stress}}{\text{Required Stress}}$$

Where Allowable Stress is determined via ASTM D 3886

- 16.12 Settlement Potential: Provide calculations to estimate the total and differential settlement of the foundation soil due to stresses imposed by the liner system.
- 16.13 Bearing Capacity and Stability: Provide estimates of bearing capacity and stability of the foundation soil during construction. Calculations/evaluation must be provided to indicate that allowable bearing capacity of foundation soil will not be exceeded. A minimum FS of 2 is recommended for bearing capacity. This FS was based on dead load conditions.
- 16.14 Potential for bottom heave and blow-out: Provide estimates of the potential for bottom heave or blow-out due to unequal hydrostatic or gas pressure. This information is needed to ensure that subgrade/subbase does not cause any problems within the composite liner. "Heave" means the upward movement of soil caused by expansion or displacement caused by the following phenomena:
 - Moisture absorption
 - Frost action
 - Removal of overburden
 - Loading of an adjacent area.
- 16.15 Waste settlement analyses: This analysis is needed to evaluate the potential for final cover liner (GM) elongation due to total and differential settlement of the waste. It should be noted that due to lack of well documented settlement of solid waste, a value of approximately seven to fifteen percent

(7 - 15%) (Reference 17, p. 413, and Reference 3, p. 76, respectively) of the solid waste height may be used for this calculation.

16.16 Leachate collection pipes must be carefully evaluated for the following:

- deflection
- buckling
- crushing _____

16.17 Wind uplift forces: (See Reference 3) Calculate the required sandbag/tire or other anchoring means spacing during placement/installation of the GM panels. FS of 1.1 (short-term only) is recommended.

Suggested Analysis Procedure:

- a. Required material properties
Geomembrane unit weight (density) (ASTM D 792)
- b. Use site-specific data to define maximum wind speed.
- c. Determine wind uplift forces from appropriate references.
- d. Calculate sandbag/tire spacing
 - Weight of sandbag/tire must be known.

$$\text{FS} = \frac{\frac{\text{Wind Uplift Forces}}{\text{Weight of Sandbags}} \times \text{Tributary Area}}{\text{Actual Field Tributary Area}}$$

16.18 Wheel loading: Calculations must be provided to verify that the wheel loading on the ramp area will not damage the GM. FS of 3 @ 10% penetration is recommended. As an alternative, the California bearing ratio and flexible pavement design approach may be used. There is a concern regarding abrasion problems on the ramp. Generally, a geotextile may be placed on top of the GM as a cushion.

Suggested analysis procedure:

- a. Required material property
 - GM compressive strength - compression test
 - Roadway subbase friction angle - triaxial test
- b. Find the field contact stress based on the type of equipment used and the roadway thickness. Assume 2:1 (vertical to horizontal) for stress distribution.
- c. Measure GM compressive strength.

d. Find FS:

$$FS = \frac{\text{Compressive Strength of GM}}{\text{Contact Stress}}$$

16.19 Stability of Soil Cover -

A slope stability analysis that follows the requirements outlined in Table 1 of this subdivision must be performed. Any geosynthetic materials installed on landfill slopes must be designed to withstand the calculated tensile forces acting upon the geosynthetic materials. The design must consider the minimum friction angle of the geosynthetic with regard to any soil-geosynthetic or geosynthetic-geosynthetic interface.

TABLE 1
Minimum Values of Safety Factors for Slope Stability Analyses

Consequences of Slope Failure	Uncertainty of Strength Measurements	
	Small ₁	Large ₂
No imminent danger to human life or major environmental impact if slope fails	1.25 (1.2)*	1.5 (1.3)*
Imminent danger to human life or major environmental impact if slope fails.	1.5 (1.3)*	2.0 or greater (1.7 or greater)*

¹The uncertainty of the strength measurements is smallest when the soil conditions are uniform and high quality strength test data provide a consistent, complete and logical picture of the strength characteristics.

²The uncertainty of the strength measurements is greatest when the soil conditions are complex and when the available strength data do not provide a consistent, complete and logical picture of strength characteristics.

*Numbers without parentheses apply for static conditions and those within parentheses apply to seismic conditions.

17. Content of documentation report: At a minimum, the following information must be provided and/or addressed in the as-built plan or report:
- 17.1 A document index and table of contents; a plan view of the entire facility to show construction progression (or area of the facility that has been constructed with its acreage);
 - 17.2 Soil liner grades (GM); soil lift compaction test results, laboratory and in-situ hydraulic conductivity test results; statistical verification and certification by a registered engineer;
 - 17.3 Leachate collection pipe invert elevation;
 - 17.4 Drainage layer depth and protective cover checks. This could be a table or a contour map to show the elevation;
 - 17.5 Leachate collection lines, clean outs and manholes with spot elevation not more than fifty (50) feet along the leachate collection lines and at all manhole entrances and exists; sump invert elevation;
 - 17.6 All monitoring devices; equipment specifications and warranties;
 - 17.7 Document all testing (and locations) conducted during the construction, in addition to calibration of test equipment;
 - 17.9 At a minimum, two cross-sections, one north-south and one east-west, throughout the completed area;
 - 17.10 Dated photographs of phases of construction, videos taken during the construction, if applicable;
 - 17.11 A comprehensive narrative explaining how the construction of the leachate collection system, GM

and soil liner was accomplished. The results of all appropriate soil analyses must accompany a report, including daily inspection reports, daily summary, inspection sheet (form), problem identification and corrective action;

At a minimum, some type of form/table must be developed to show the following information.

- a) GM manufacturer's certification and certificate analysis:
 - Roll number
 - GM specification as required by design specifications
 - Resin specification as required by QC/QA plan.
- b) Drawing/certification:
 - GM panel layout
 - Liner penetration locations
 - Record drawing of sump
 - Seam locations
 - Defect and repair locations
 - Certificate of acceptance of soil subgrade by QA officer or installer.
- c) Trial weld information:
 - Date
 - Time
 - Ambient temperature
 - Type of welds
 - Shear and peel test results
 - Other information as appropriate
- d) Panel placement:
 - Panel dimension and panel number
 - Date, time and roll number
- e) Panel seaming:
 - Date, time and seam ID number
 - Panel number and seam length
 - Weather conditions, etc.
- f) Nondestructive testing:
 - Date, time (start/end) and pressure (start/end)
 - Seam number
 - Pass and fail results
- g) Destructive testing:
 - Date, sample, ID seam number
 - Field/lab peel and shear test
 - Pass and fail test results
 - Location of test
- h) GM seam laboratory:
 - Test results for peel and shear test
 - Sample ID number
 - Seam number and sample size

- Maximum load and type of welds
- Other information as appropriate

- i) Repairs reports:
 - Date, panel number
 - Pass/fail test results
 - Location of repair and the patch size
 - Other information as appropriate

- 17.12 Any deviations from the approved CQC/CQA plan must be noted and explained.
- 17.13 Results of an initial leachate collection system cleanout prior to landfilling of an area.
- 17.14 Results of leak testing of leachate storage tanks, if applicable;
- 17.15 Final cover design with drawings, methane gas vents, if applicable;
- 17.16 System cross-section, as necessary;
- 17.17 Details as necessary for clarification purposes;
- 17.18 Methane gas monitoring system; if applicable
- 17.19 Other site information as appropriate or as required by permit; seismic impact zone determination (if applicable);
- 17.20 Additional information as may be required by staff.

NOTE 1: It should be noted that the recommended factor of safety for engineering analysis in the document may be increased or decreased. A lower factor of safety may be allowed if it is demonstrated that an adequate level of protection is provided.

NOTE 2: The Commissioner may require other information which may not be included in this document to insure compliance with the current rule. The Commissioner also may allow alternative testing and calculations as long as they provide comparable information.

This guidance may be modified periodically to reflect changes in methodology. If you have any questions regarding this guidance, please contact Solid Waste Engineering staff of this office for assistance.

Attachment: Bibliography

TABLE 1
GEOMEMBRANE RECOMMENDED MINIMUM TESTING FREQUENCIES

ITEM	TESTING	FREQUENCY
1. Conformance Testing (Upon shipment of Geomembrane to the Site)	<ul style="list-style-type: none"> - Thickness - Tensile Characteristics - for Strength and Elongation at Yield and Break - Carbon Black Content - Carbon Black Dispersion 	5 tests per roll evenly distributed Every 50,000 sq. ft. or one per lot. A lot is a group or consecutively numbered rolls or panels from the same manufacturing line.
2. Destructive Test/Shear and Peel Test		Every 500 linear feet (if fusion weld) and every 400 linear feet (If extrusion weld)
3. Nondestructive Test		Testing must be performed on all seams over their full length.
4. Seaming Equipment & Crew Test Weld		<p>Checked daily by sample - One in the morning (8:00 a.m. preferred) and one in the early afternoon (12:30 p.m. preferred and whenever the seaming equipment is shut off for more than 30 minutes at the ambient temperature. Minimum 5 feet continuous seam.</p> <p>Test weld strips will also be required whenever personnel or equipment are changed and/or when weather conditions cause wide temperature fluctuations in the geomembrane. Peel and shear tests must be performed within 30 minutes of completion of the test strip.</p>
5. Overlap		Per manufacture's recommendation; but not less than 3 inches for extrusion welding and 5 inches for fusion welding.
6. Testing Equipment Calibration		Per Manufacturer's recommendation.
7. Acceptance and Rejection Criteria for destruction test		Each test location must pass; however, if sets of 5 tests specimens are performed for each test location, eighty percent (80%) must pass.
8. In the event of test failure		Test must be performed at a distance of ten (10) feet on each side of the failure point or as provided in the CQ document.
<p>Note:</p> <ol style="list-style-type: none"> 1. All conformance/acceptance testing must be reviewed, accepted and reported by a CQA engineer <u>before</u> deployment of the geomembrane. 2. Failing conformance tests will be subject to ASTM D-4759, "Determine the Specification Conformance of Geosynthetics". 3. Most of the requirement of item no. 1 is applicable only to HDPE geomembrane. For other geomembranes, refer to NSF 54 standards or other applicable standards. 4. The required testing frequencies listed in this table may be revised by the engineer/CQA officer to reflect new or revised test methods, or to conform with improvements in the state-of -the-art practice. The IDEM Engineering staff must be consulted prior to any revisions being made to this list. 		
All testing must be performed in accordance with the American Society for Testing and Materials (ASTM)		

TABLE 2

	Geomembrane	Geonet	Geotextile
Material Specifications	x	x	x
Transmissivity		x	x
Permitivity		x	x
Filter-Retention			x
Filter -Clogging			x
Strength-Settlement	x	x	x
Strain-Settlement	x	x	x
Tensile Stress-Downdrag	x	x	x
Localized Subsidence	x	x	x
Slope Stability	x	x	x
Wheel Loading	x	x	x
Construction Specifications	x	x	x

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